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ASSESSING POTENTIALLY AVAILABLE SOIL NITROGEN TO IMPROVE NITROGEN FERTILIZER RECOMMENDATIONS

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Assessing Potentially Available Soil Nitrogen to Improve Nitrogen Fertilizer Recommendations

Final Report
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(a) ABSTRACT

Most soils contain several thousand kilograms of nitrogen (N) in an organic form, both as a component of the soil organic matter and as newly added crop residues. When this material is decomposed, N in organic forms is released, or "mineralized", and is thus available for plant uptake. The question is, how much N is released during the growing season? We examined various soil availability indices with the goal of identifying and investigating an appropriate measure of available soil N for Saskatchewan soils. Ultimately, our goal is to accurately estimate the N contribution of N from the soil organic pool, and adjust fertilizer N recommendations for wheat and canola accordingly, thereby matching crop N requirements with N supply from both the soil and fertilizer sources.

(b) EXECUTIVE SUMMARY:

Currently, many soil-testing labs in Western Canada base their fertilizer N recommendations on a measure of available inorganic-N, i.e., N that already has been mineralized or N that remains in the soil after a crop has been harvested. Although this N is certain to contribute to the N nutrition of subsequent crops, it may still be useful to estimate the potentially large, and variable, contribution that the soil organic matter can make to the total N availability during the growing season. Indeed, given the growing use of reduced tillage and the inclusion of legumes into rotations, it seems possible that N contributed from the soil organic pool during the growing season could overwhelm the contribution of inorganic N normally measured in the fall or spring. But can we accurately estimate N release from the organic N pool to improve fertilizer N recommendations?

Our project was initiated to examine various methods to estimate potentially available N. We hypothesized that a measure of potentially available N could more accurately represent the soil N status and thus could be used to provide a better estimate of fertilizer N requirements for wheat and canola, particularly on soils with a high N supplying power. In particular, we were interested in examining an estimate of potentially available N proposed by Khan et al. (2001), commonly known as the 'Mason Jar Method' and 'Illinois N Test' and the 'Amino Sugar N-test' (ASN). Khan et al. (2001) described their diffusion method to determine different forms of N in soil, one of which (i.e., amino sugar N) was closely related both with check yield and fertilizer N

response. Although this soil testing estimate of potentially available N has been adapted by a number of soil testing labs that service western Canada, little information regarding the applicability of this test to Saskatchewan soils currently is available. The purpose of our study was to assess the utility of the ASN test for Saskatchewan soils and investigate relationships between this measure of potentially available N and yield of wheat and canola

Initially, the specific objectives of the project were as follows:

1) To assess a suitable and agronomically meaningful test for estimating potentially available soil N;

2) To develop preliminary fertilizer N recommendations for wheat and canola based on an appropriate soil N availability index.

The study was conducted according to the modified proposal (Addendum to Appendix A) which allowed us to reanalyze soil samples collected from previous studies in which yield, and yield response of wheat and canola to fertilizer N, was determined. We then related this data to the new measure of potentially available N, i.e., ASN, as described by Khan et al. (2001).

The study was carried out in the following stepwise manner:

1) Standardization and development of laboratory protocols for the 'in-house' use of the ASN test.
2) Comparison of the ASN test to other measures of potentially available N.
3) Assessment of the ASN test for predicting wheat yield and N fertilizer response, and the development of preliminary production functions for wheat.
4) Assessment of the ASN test for predicting wheat yield and N fertilizer response, and the development of preliminary production functions for wheat.
5) Assessment of the ASN test over a range of soil types and uses.

The study generated considerable interest in the agricultural/research community. Specifically, I was invited to discuss the topic of soil N availability indices and describe our research at a number of different agronomist meetings (Manitoba Agronomists Conference 2002, 2003 CAAR Crop Management Forum, the 2003 Western Canada Agronomy Workshop, 2005

Saskatchewan Soil Conservation Association Annual Conference and the 2005 Canola College) and presented a volunteered paper with some preliminary findings at a fourth meeting (Soils and Crops Workshop, 2003). Additionally, a graduate student (Shelagh Torrie) working on this project presented posters at both the 2004 American Society of Soil Science meetings and the 2005 Soils and Crops Workshop. The support from the Government of Saskatchewan, ADF, was acknowledged in these presentations.

(c) TECHNICAL REPORT

Project Activities:

1) **Standardization and development of laboratory protocols for the 'in-house' use of the amino sugar N test.**

Considerable time was spent at the initiation of the project standardizing laboratory techniques and developing appropriate laboratory protocols based on the published literature. This standardization procedure was greatly enhanced through our collaboration with laboratory personnel at AGVISE Labs (Larry Wickoff). The greatest challenge we faced was achieving acceptable reproducibility and we initially struggled with data that were highly variable. Ultimately, we found that the success of the ASN test was largely dependent on the heat source used to maintain samples at the required temperature during sample processing. Indeed, although we attempted to use a number of standard laboratory equipment to provide heat, we remained unsuccessful until we used a comparable heating element to that described in the Technical Note 02-01 (Department of NRES, University of Illinois at U-C). Discussions with others such as Larry Wickoff (AGVISE Labs) and various researchers who have been using this method routinely in their labs (i.e., attendees at the American Society of Soil Science Annual meetings) have confirmed that the application of heat to the soil samples is critical to the success of the method and, in our hands, the direct heat provided by the commercial griddle was superior to more diffuse heat provided by laboratory equipment including sand baths, oil baths and standard laboratory heating plates.

2) **Comparison of the ASN test to other measures of potentially available N.**

Having successfully developed our 'in-house' ASN protocols, we were able to conduct an assessment of the suitability of this soil N availability index as compared to other measures of potentially available N. Soils used in this evaluation were collected as a component of a previous study (Yates, 2001), and were re-analyzed for the purposes of the current investigation. Specifically, we examined the relationship between ASN (Mulvaney and Khan, 2001), hot KCL-N (Jalil et al., 1996), inorganic N and various biological indices of available N, and the yield of wheat (determined during a 1998 study) along a 100-point sampling transect in the Black soil zone.

Materials and Methods

The experimental design and sampling protocol used in this study were previously described (Walley et al., 2002). Briefly, the study site was located in the Thin Black soil zone near Hepburn, Saskatchewan, Canada (106°41'W, 52°25'N) on a ridged hummocky morainal surface with average slope gradients ranging from 6 to 9%. The parent materials are medium to moderately fine-textured moderately to strongly calcareous, unsorted glacial till. The field had been cropped with wheat for the previous two years using zero tillage management.

A single 300-m north-south transect, consisting of 100 sampling points at 3-m intervals, was selected. The sampling points and surrounding area were surveyed using a total station laser theodolite (Model Set 5, Sokkisha Co. Ltd., Japan). Soil samples were collected on 4-5 May 1998. Soil cores, 6.5 cm in diameter, were taken to a depth of 60 cm in three increments (0 - 15 cm, 15 - 30 cm, and 30 - 60 cm). Samples were dried, ground and stored at room temperature until they were analyzed in 2002. Data relating to the 0-15 cm soil depths are presented here.

Hard red spring wheat (*Triticum aestivum* var. AC Barrie) was seeded on May 15th at a rate of 90 kg ha^{-1} and fertilized with monoammonium phosphate, supplying P_2O_5 at a rate of 27.5 kg ha^{-1} and N at a rate of 5.5 kg ha^{-1}. No additional fertilizer-N was applied. A second strip of wheat fertilized with an additional 70 kg N ha^{-1} was seeded immediately adjacent to the non-N strip. At crop maturity on 3 September 1998 a 1-m^2 yield sample was hand harvested at each sampling point, dried to constant weight at 60°C, weighed, and threshed. Grain and straw yield, and N uptake were determined.

Soil Nitrogen Availability Indicators

In the original study, several soil N availability indicators were examined and have been described (Walley et al., 2002) including: (i) cumulative N released during a two-week aerobic incubation (N_{MIN}); (ii) potentially mineralizable N estimated using a sixteen-week aerobic incubation (N_0); (iii) NO_3 sorbed on anion exchange membranes (NO_{3AEM}); (iv) N extracted with hot 2 M KCl (N_{KCl}); and (v) N hydrolyzed with hot 2 M KCl (N_{HYDR}). Nitrate sorbed on anion exchange membranes (NO_{3AEM}) (PRS™, Western Ag Innovation, Saskatoon, Canada) were used to estimate N availability for the three depths in the laboratory, according to Qian and Schoenau (1995). Inorganic-N extracted with hot 2 *M* KCl (N_{KCl}) was determined using a modification of the method described by Gianello and Bremner (1986). Nitrogen hydrolyzed using hot 2 *M* KCl (N_{HYDR}) was calculated by subtracting the quantity of inorganic N extracted with 2 *M* KCl at room temperature from the amount in the heated extract (Wang et al., 2001). Results relating to these soil N availability indices were previously reported (Walley et al., 2002).

We re-analyzed the stored soils collected in 1998 for amino-sugar N using the method described by Khan et al. (2001), hot KCL-N (Jalil et al. , 1986) and inorganic N (Keeney and Nelson, 1982). To determine amino-sugar N, 1 g of air-dried soil was treated with 10 mL of 2 N NaOH in a wide-mouth Mason jar, and the sample was heated for 5-h at 50°C on a commercial griddle. Liberated NH_3 (NH_4 + amino-sugar N) was collected in H_3BO_3 and subsequently determined by titration.

Results and Discussion

Climatic conditions in 1998 were characterized by a relatively hot and dry early growing season followed by more favorable conditions during June (Table 1).

Table 1. Precipitation and average air temperature for the 1998 growing season at Hepburn.

Growth Period	Average air temperature (°C)	Precipitation[†] (mm)
Seeding (May 15) to May 31	17.2	1.8
June	14.8	86.2
July	18.3	34.2
August (Harvested Sept. 3)	19.4	42.2

[†]Thirty-year (1959-1987) average growing season precipitation is 173 mm.

Relative elevation along the transect across the ridged hummocky morainal surface varied within a range of 1.5 m with average slope gradients ranging from 6 to 9%. Thus, although topography was variable along the transect, the site was not characterized by extreme topographic variation. Interestingly, even these relatively moderate topographic variations strongly influenced a number of soil and plant growth characteristics. For example, a negative relationship existed between relative elevation and spring soil available moisture (Fig. 1). In contrast, no significant correlation existed between relative elevations and spring inorganic N (r=0.19 n.s.) (Fig. 2) or total organic C (r=-0.114 n.s.) (Fig. 3).

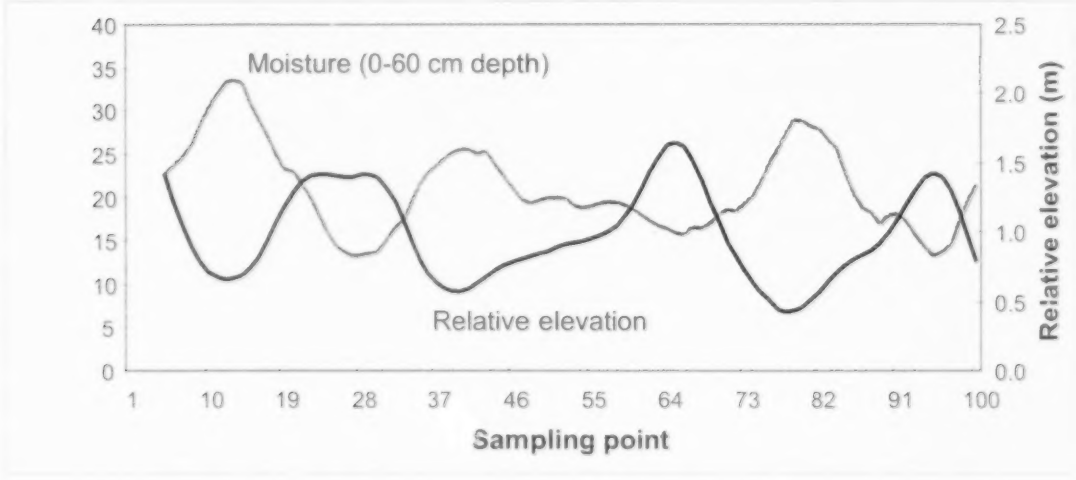

Figure 1. Relationship between relative elevation and spring soil moisture at Hepburn, Saskatchewan, 1998.

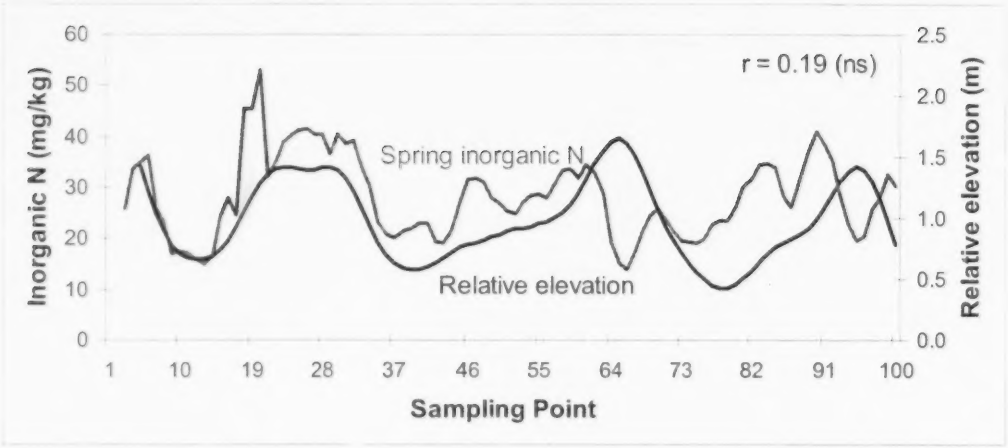

Figure 2. Relationship between relative elevation and spring inorganic N at Hepburn, Saskatchewan, 1998.

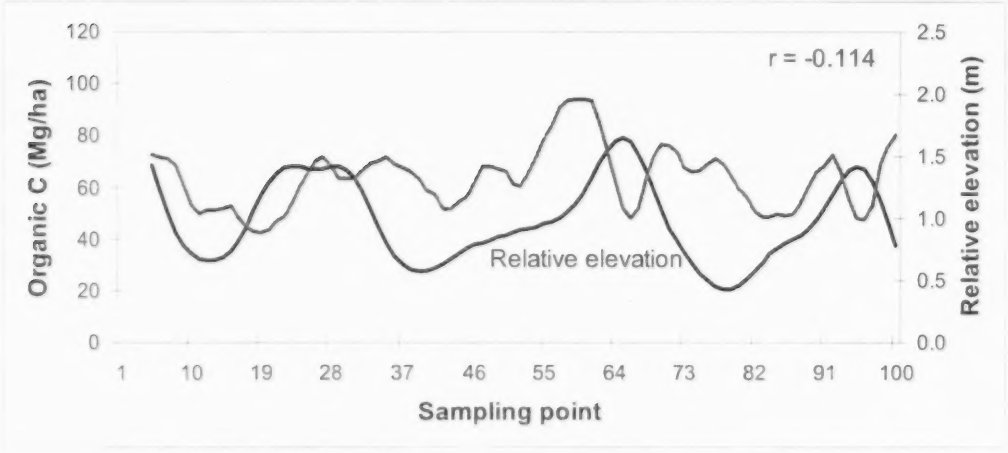

Figure 3. Relationship between relative elevation and organic C at Hepburn, Saskatchewan, 1998.

Although no significant correlation existed between elevation and soil organic C, it is interesting that a significant negative correlation existed between relative elevation and ASN (Fig. 4). This observation suggests that the controls related to topography influenced the 'quality' of soil organic matter although a correlation between the quantity of soil organic matter

within the 0-15 cm depth and elevation was not detected. Clearly elevation itself was not directly influencing soil organic matter quality; rather, it was an indirect effect of elevation on some factor or factors that ultimately control organic matter quality. It seems likely that the influence of topography on soil moisture redistribution within the landscape was subsequently influencing organic matter inputs and cycling within the landscape, and thus exerted an influence on the levels of ASN.

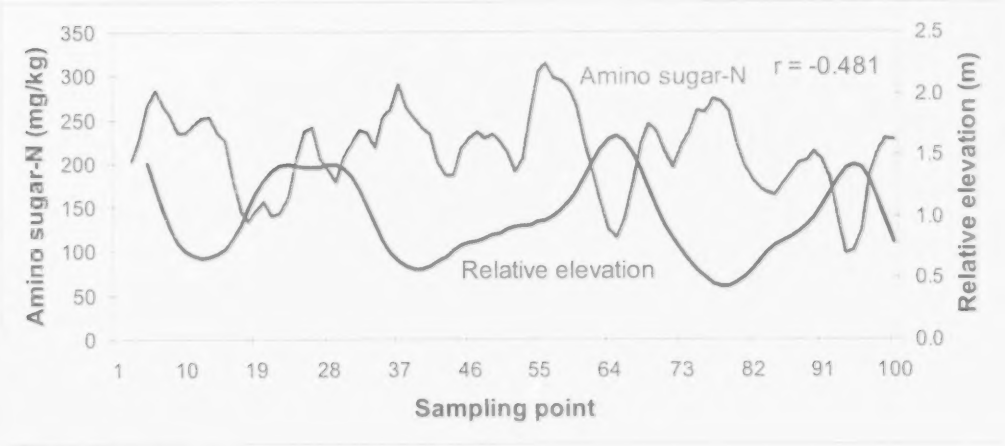

Figure 4. Relationship between relative elevation and amino sugar-N at Hepburn, SK.

Amino sugar N was found to be positively correlated with the unfertilized (N) yield of spring wheat (Fig. 5). The correlation ($r=0.566^*$) was highly significant ($p=0.05$). Moreover, this correlation was higher than correlations between unfertilized yield and any of the other N availability indices previously examined (Walley et al. 2002). For example, the correlation with hot KCl-N, although significant, was $r=0.472^*$ (Fig. 6) whereas inorganic-N was not significantly correlated with yield of unfertilized wheat (Fig. 7). These results indicate that of the soil N indices tested, the ASN test appears to have the greatest potential for describing N availability for Saskatchewan soils. Indeed, when compared to other measures of potentially available N, including biological aerobic incubation, the ASN test (0-15 cm) was most highly correlated to both unfertilized grain yield and N uptake (Table 2).

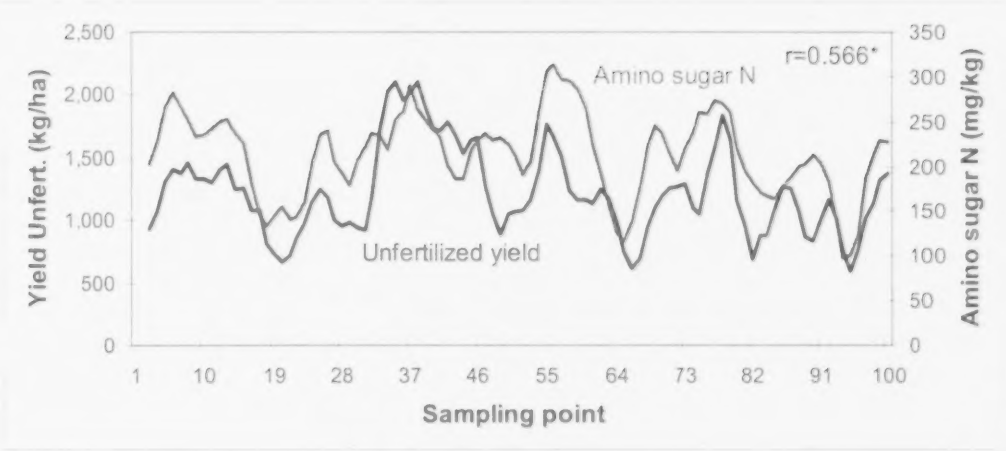

Figure 5. Relationship between unfertilized (N) wheat yield and amino sugar-N in soils from Hepburn, Saskatchewan.

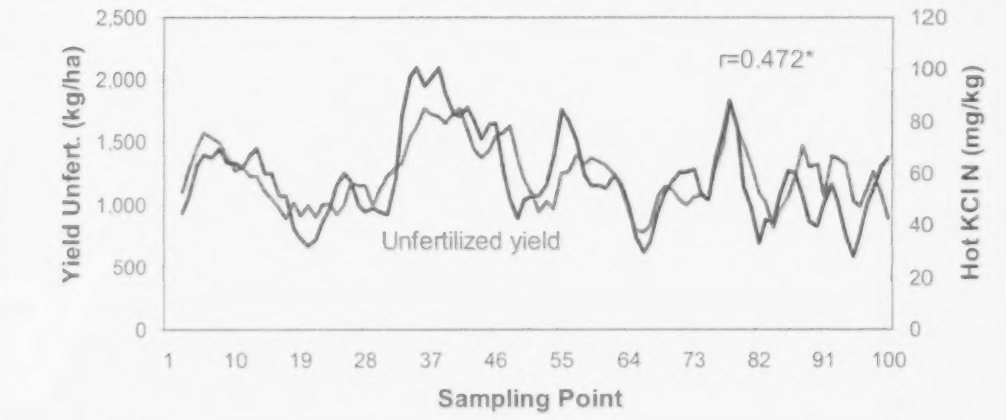

Figure 6. Relationship between unfertilized (N) wheat yield and hot KCl-N in soils from Hepburn, Saskatchewan.

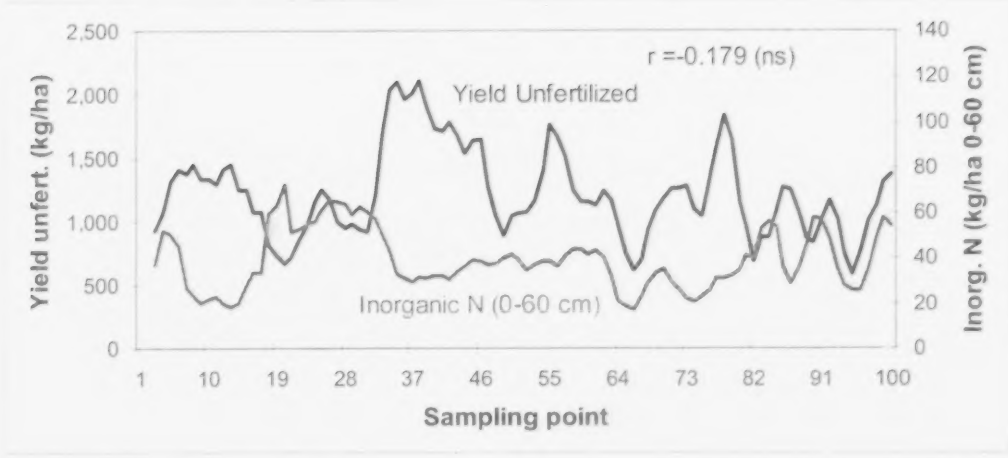

Figure 7. Relationship between unfertilized (N) wheat yield and spring inorganic-N in soils from Hepburn, Saskatchewan.

Table 2. Pearson correlations for various measures of potentially available N and grain yield and N uptake of unfertilized wheat grown at Hepburn, 1998. Only significant correlation values are reported.

Variable	Grain yield	N uptake
Spring Inorganic N	n.s.	n.s.
Total N	n.s.	n.s.
Total C	0.356***	0.436***
Ion Exchange membrane N	0.367***	0.319***
16-wk aerobic incubation N	0.208*	n.s.
2-wk aerobic incubation N	0.328**	0.373***
Hot KCl N	0.472***	0.481***
ASN	0.566***	0.625***

*, **, ***Significant correlations at the 0.05, 0.01 and 0.001 probability levels.

We also examined the relationship between ASN levels and other measured soil characteristics and N availability indices. Pearson correlations suggest that ASN was most closely related to organic C levels. Surprisingly, relationships with biological incubation mineralization assays (16- and 2-week), frequently assumed to be favored methods for assessing potential N mineralization, were not as strong, although statistically significant (Table 3).

Table 3. Pearson correlations for various measures of potentially available N and ASN levels for soils collected at Hepburn, 1998.

Variable	ASN (0-15 cm)	ASN (15-30 cm)
Spring Inorganic N	n.s.	n.s.
Total N	n.s.	n.s.
Total C	0.356***	0.436***
Ion Exchange membrane N	0.367***	0.319***
16-wk aerobic incubation N	0.208*	n.s.
2-wk aerobic incubation N	0.328**	0.373***
Hot KCl N	0.472***	0.481***
ASN	0.566***	0.625***

*, **, ***Significant correlations at the 0.05, 0.01 and 0.001 probability levels.

Conclusions:

Correlations between measured ASN levels and unfertilized yield suggest that this relatively new soil N test may be useful for assessing potentially available N in Saskatchewan soils. We were particularly pleased to observe that of all the soil N availability indices tested (additional indices previously reported in Walley et al., 2002), the ASN test had the highest correlation coefficient with wheat yield and N uptake. Moreover, because the data used in the correlations were collected over a transect that extended across a number of different landscape positions, and thus different soils, we are encouraged to note that the relationships apparently were relatively consistent, irrespective of differences in various soil characteristics. Levels of ASN apparently are controlled, in part, by levels of organic C. However, data suggest that both the size and the quality of the organic C pool may control ASN levels.

On the basis of these results, we elected to focus on the ASN test as a measure of potentially available soil N for Saskatchewan soils. Our next step was to re-analyze soils from a number of

studies that previously had been collected as a component of various field investigations in which yield responses of wheat and canola to fertilizer N had been measured. Our objective (i.e., Objective 2) was to confirm that theASN test provided an appropriate measure of available N for wheat and canola and to develop preliminary fertilizer N production functions for wheat and canola based on this soil N availability index.

3) Assessment of the ASN test for predicting wheat yield and N fertilizer response, and the development of preliminary production functions for wheat.

The soils used in this portion of the study were collected during an extensive AFIF/ADF variable rate study for wheat and canola, and were analyzed for ASN according to the 'in-house' protocol developed as a consequence of Objective 1 activities. The initial experiments, conducted in Saskatchewan, examined the responsiveness of wheat in different landscape positions to N fertilizer additions. Failure to obtain a strong relationships between the traditional spring soil nitrate test and grain yield suggested the need for a soil test measurement that can more accurately predict the N-supplying power of a wide range of soils, thereby providing the impetus for the current study.

Having confirmed a promising measure of soil N availability (i.e., the ASN test) using the samples collected from the Hepburn transect, we analyzed soil samples, representing diverse soil zones and productivity potentials previously collected as a component of AFIF/ADF variable N rate fertilizer trials.

Materials and Methods

The initial experiment was conducted over three growing seasons on four hummocky glacial landscapes located at Outlook, the Conservation Learning Centre (CLC), Swift Current and Watrous. The sites were chosen to represent major soil zones and agricultural areas of Saskatchewan (Table 4). The Outlook site was chosen to represent dryland irrigation production in the province. Landforms at each field site were segmented into upper-, mid- and lowerslope positions with the exception of the CLC site, which contained upper- and lowerslopes but no distinguishable midslopes. Plots were seeded to 'AC Barrie' wheat and fertilized with 0, 0.5, 1.0, 1.5, and 2.0 times the recommended N fertilizer rate based on standard soil test

recommendations. Treatments were replicated in a randomized complete block design in which each block covered all landscape positions (Fig. 8). Variable rate phosphorus fertilization was also studied in the experiment, although the following discussion is limited to N only. A more complete description of the experimental sites and methods can be found in Pennock and Walley (Available online at http://www.agr.gov.sk.ca/afif/Projects/19960130.pdf).

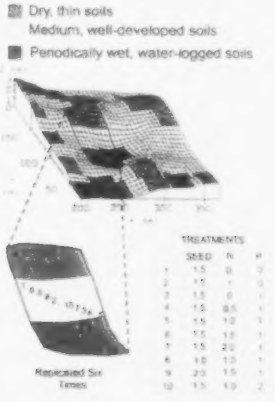

Figure 8. Experimental design (Pennock and Walley, 2000)

Inorganic-N (NO_3^- and NH_4^+) was extracted from spring soil cores in each plot using the 2.0*M* KCl extraction method of Keeney and Nelson (1982). Soil organic carbon (SOC) was determined through dry combustion in a furnace at 840°C. Amino sugar-N (0- to 30-cm soil depth) was determined using the Illinois ASN test as described by Khan et al. (2001).

Yield response for each replicate was determined using the formula:

Yield response=100*(Maximum yield-Unfertilized yield)/Unfertilized yield **(Eq. 1)**

Inorganic-N values for each plot were averaged across each replicate. Pearson correlation analysis was used to determine the relationships between soil and yield parameters. Stepwise regression models were developed to predict yield response. The independent variables used in the models included NO_3^-, ASN, A-horizon depth, depth to carbonates, soil organic carbon

(SOC), spring soil moisture (θ_v), spring plant available moisture, crop water use, and growing season precipitation (GSP).

Results and Discussion

Each experimental site had unique soil and growing season properties (Table 4). On average, the CLC site had the highest NO_3^-, ASN, and SOC values, while the Swift Current site had the lowest.

Table 4. Description of experimental sites used in the wheat study.

Site	Year	Growing Season Precipitation (cm)	Nitrate-N (0-60 cm) Kg ha^{-1}	SOC (0-30 cm) Mg ha^{-1}	ASN (0-30 cm) mg N kg^{-1}
CLC	1997	21.7	61.1	40-204	197-403
Thick Black Soil Zone	1998	31.6	49.8	46-192	129-395
Hummocky glaciolacustrine	1999	34.7	83.6	23-205	89-492
Outlook	1997	29.4	60.7	34-78	143-213
Dark Brown Soil Zone	1998	34.9	41.4	40-94	123-243
Undulating glaciolacustrine	1999	19.5	79.9	43-67	150-224
Swift Current	1997	18.3	26.1	18-59	62-172
Brown Soil Zone	1998	17.7	20.5	13-76	74-241
Hummocky glacial till	1999	14.0	28.2	13-102	46-270
Watrous	1997	16.4	29.0	33-147	138-320
Dark Brown Soil Zone	1998	21.3	44.6	26-124	105-275
Hummocky glacial till	1999	19.5	76.2	18-96	75-349

Amino sugar-N was significantly correlated to unfertilized yield and yield response although the strength of the relationships was not greatly improved over NO_3^-, particularly in the 0- to 30-cm depth (Tables 5 and 5). Amino sugar-N was better correlated to yield response that to unfertilized yield in all landscape positions (Table 5). The strength of the correlation between ASN and both yield response and unfertilized yield followed the sequence upperslope > midslope > lowerslope.

At the CLC site, where SOC levels were the highest, there were no significant correlations between yield response and NO_3^- (Table 6), whereas the correlation between ASN and yield response was relatively strong. Amino sugar-N may be a better predictor of responses to

fertilizer when the high N-supplying power of the soil can overwhelm initial inorganic-N levels. Higher correlations between yield response and NO_3^- at Watrous may be a result of below average rainfall, which would limit the turnover of the organic-N pool. As suggested by Khan et al. (2002), the Illinois ASN test may be an unreliable predictor under non-normal growing conditions.

Table 5. Pearson correlations between soil N indices and wheat yield parameters within the entire data set and landscape positions.

	All Data		Upperslope		Midslope		Lowerslope	
	Yield	Yield Response	Yield	Yield Response	Yield	Yield Response	Yield	Yield Response
Nitrate-N (0-30 cm)	0.493**	-0.455**	0.477**	-0.425**	0.664**	-0.537**	0.442**	-0.461**
Nitrate-N (0-30 cm)	0.194**	-0.034	0.585**	-0.534**	0.076	-0.283*	0.237*	-0.266*
Nitrate-N (0-30 cm)	0.409**	-0.286**	0.551**	-0.494**	0.294*	0.048	0.370**	-0.396**
ASN (0-30 cm)	0.399**	-0.519**	0.526**	-0.651**	0.329*	-0.475*	0.262*	-0.462**

*, **, ***Significant correlations at the 0.05, 0.01 and 0.001 probability levels.

Table 6. Pearson correlations between soil N indices and wheat yield parameters within sites.

	CLC		Outlook		Swift Current		Watrous	
	Yield	Yield Response	Yield	Yield Response	Yield	Yield Response	Yield	Yield Response
Nitrate-N (0-30 cm)	0.539**	-0.233	0.484**	-0.429**	0.716**	-0.509**	0.527**	-0.448**
Nitrate-N (0-30 cm)	0.239	-0.248	0.785**	-0.668**	0.401**	-0.048	0.339*	-0.435*
Nitrate-N (0-30 cm)	0.508**	-0.266	0.664**	-0.577**	0.651**	0.306*	0.490**	-0.467**
ASN (0-30 cm)	0.455**	-0.525**	0.403**	-0.393**	0.714**	-0.552**	0.527**	-0.338*

*, **, ***Significant correlations at the 0.05, 0.01 and 0.001 probability levels.

Interestingly, the data suggest that sampling to 60 cm (Soper and Huang, 1963) offered no advantage over the 0- to 30-cm depth for inorganic-N in the landscape positions (Table 5). However, at the Outlook site (Table 6), NO_3^- leaching as a result of irrigation was evident as indicated by the high correlations between yield and NO_3^- at the 30- to 60-cm depth as opposed to the 0- to 30-cm depth. Similarly, the 0- to 30-cm depth used for ASN may not adequately capture the depth of N influence at that site.

The parameters included in the stepwise regressions developed to predict yield response were not consistent between sites (Table 7). This indicates that the interaction of these parameters at each site have differing effects on wheat yield. In a stepwise regression variables are entered into the model if their inclusion significantly ($p<0.05$) improves the model R^2, and are removed if their removal does not significantly ($p<0.1$) decrease the R^2. Low model R^2 values indicates that although a range of predictor variables was applied to the model, the parameters were unable to account for much of the yield variability at each site. Walley et al. (2001) found that yield response to N fertilizer was relatively unpredictable between years and landscape positions, and that this variability can be attributed in part to the dual role of N in both grain yield and protein increases.

Surprisingly, ASN was included in the stepwise equations only at the Watrous site, although significant correlations had suggested that this measure of potentially available N was correlated with seed yield of wheat. However, it is conceivable that the ASN, together with one or more

other soil variables, may have had similar explanatory power and variance that was not distinguishably different from one anther. Thus, in the stepwise regression, inclusion of ASN apparently did not improve the overall model, despite relatively good correlations with wheat yield.

Table 7. Results of stepwise regression equations for prediction of yield response.

	Parameter Estimate	Standard Error	F-value	Partial R^2	Model R^2
All data	239.64	19.321			
	-0.506	0.079	72.088	0.269	0.269
	-0.857	0.15	55.289	0.093	0.362
	1.603	0.553	39.844	0.019	0.381
	-1.798	0.693	32.451	0.021	0.402
CLC					
Intercept	184.64	28.674			
SOC (0-15 cm)	-1.476	0.337	16.484*	0.327	0.327
Nitrate-N (0-60cm)	-0.613	0.279	11.583*	0.086	0.412
Outlook					
Intercept	16.432	50.124			
Precip. (growing season)	3.388	1.261	42.598*	0.450	0.450
Nitrate-N (30-60 cm)	-2.614	0.999	27.116*	0.065	0.515
Swift Current					
Intercept	275.83	28.249			
SOC (0-30 cm)	-2.903	0.577	25.322*	0.327	0.327
Watrous					
Intercept	64.139	49.506			
Nitrate-N (0-60 cm)	-1.044	0.242	14.510*	0.218	0.218
ASN	-0.404	0.122	10.671*	0.077	0.295
Soil water θ_v(0-30 cm)	4.559	1.85	9.844*	0.076	0.371

*Significant at < 0.0001 probability levels.

Summary

Wheat yield response was a function of spring inorganic-N (NO_3^-), soil moisture (growing season precipitation, volumetric water content), and soil organic matter, although the contribution of any single parameter varied between sites. Relatively low R^2 values for the yield response functions indicates there is still a large amount of yield variability unaccounted for by any of the predictor variables. The correlation between ASN and yield response was variable between sites and landscape positions, indicating that ASN may not be an applicable measure of

soil N fertility across the entire province of Saskatchewan. Additional research will be required before the ASN test can be adapted to wheat production in Saskatchewan.

Stepwise regressions developed to predict yield response indicated that spring nitrate levels, soil organic matter, and soil moisture are important in predicting yield response, although low R^2 values suggest a large amount of variability is still unaccounted for by these variables. Inclusion of the ASN test in the production equations failed to improve model R^2 values. These data suggest that additional research will be required before the ASN test can be adopted for wheat grown on Saskatchewan soils.

4) Assessment of the amino sugar N test for predicting canola yield and N fertilizer response, and the development of preliminary production functions for canola.

The soils used in this portion of the study were collected during an ADF/AFIF variable rate study for canola, and through a collaborative project funded by the Saskatchewan Wheat Pool. The initial experiments, conducted in Saskatchewan, examined the responsiveness of canola in different landscape positions to nitrogen (N) fertilizer additions and followed protocols previously described for wheat. A description of the sites is provided in Table 8. Additional descriptions of the sites and site characteristics are available in final ADF (http://www.agr.gov.sk.ca/apps/adfreports2/19950063.pdf) and AFIF (http://www.agr.gov.sk.ca/afif/Homepage.htm) reports. The soils were analyzed for ASN according to the protocol developed as a consequence of Objective 1 activities.

Table 8. Description of experimental sites used in the canola study.

Site	Year	Growing Season Precipitation (mm)	Site Description
Hepburn	1998 1999	243.8	Thick Black Soil Zone Hummocky glaciolacustrine
Watrous Dark Brown Soil Zone Hummocky glacial till	1998 1999	191.3	Dark Brown Soil Zone Hummocky glacial till
St. Dennis	1999		Dark Brown Soil Zone Hummocky glacial till

Results and Discussion

Pearson correlations revealed that ASN levels were typically well correlated with canola yield and responses to N fertilizer whereas spring inorganic nitrate-N levels were either not correlated or only weakly correlated with canola yield and yield responses (Table 9, Fig.9). Although there was some variability between sites with respect to the strength of the relationship between ASN and canola yield, it was clear that this measure of soil N was a useful soil N availability index for canola. It is interesting that although ASN was correlated with canola yield at Watrous (i.e., correlated with the unfertilized N check treatment), yield response to fertilizer N was not correlated to ASN levels. It can be concluded that some other factor (likely related to different climatic conditions in 1998 and 1999) controlled response to fertilizer N.

Table 9. Pearson correlations between soil N indices and canola yield parameters within sites.

	All data		Hepburn		St. Denis		Watrous	
	Yield	Yield Response	Yield	Yield Response	Yield	Yield Response	Yield	Yield Response
Nitrate-N (0-30 cm)	0.270*	-0.097	0.096	0.000	0.288	-0.221	0.300	-0.218
Nitrate-N (30-60 cm)	-0.015	0.048	-0.048	0.162	0.534*	-0.207	0.029	-0.217
Nitrate-N (0-60 cm)	0.117	-0.016	0.020	0.106	0.477*	-0.271	0.229	-0.262
ASN (0-30 cm)	0.528**	-0.449**	0.367*	-0.464**	0.689**	-0.632**	0.639**	-0.346

*, **, ***Significant correlations at the 0.05, 0.01 and 0.001 probability levels.

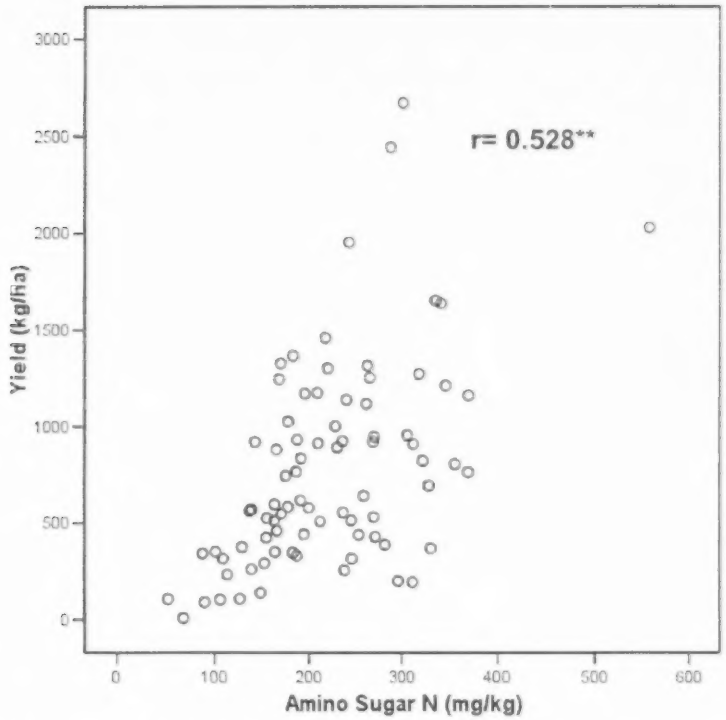

Figure 9. Relationship between ASN levels and yield of unfertilized (N) canola at three sites in Saskatchewan.

The parameters included in the stepwise regressions developed to predict canola yield response included nitrate-N, ASN and organic C when data from all sites were considered (Table 10). However, when individual sites were analyzed, ASN was the only variable retained by the stepwise regression for both the Hepburn and St. Denis data. No significant relationships were detected for the Watrous site. The significance of the ASN test for predicting yield response of canola is in contrast to the production functions developed for wheat in which ASN was included in the stepwise equations only at the Watrous site. These data suggest that there is a fundamental difference between the N nutrition of wheat and canola that apparently controlled the response of these two crops to fertilizer additions. It is interesting to note that wheat yield potential is established early in the growing season (Johnston and Fowler, 1992) and N released later in the growing season may contribute to protein levels but is unlikely to influence seed yield. Thus, if ASN measures potentially available N and this N is not released until after wheat yields have

been set, ASN is unlikely to be included in regression equations for wheat yield. In contrast, canola is characterized by morphological plasticity and is more responsive to later season N availability. Thus, if ASN does, in fact, provide an estimate of N availability throughout the growing season (i.e., potentially available N) it is reasonable that the ASN test is more closely related to canola N yields. This explanation is consistent with our observations for wheat and canola. Clearly, these data suggest that the utility of the ASN test may rest on crop N uptake patterns and thus may vary between crops.

Table 10. Results of stepwise regression equations of study sites for prediction of yield response.

	Parameter Estimate	Standard Error	F-value	Partial R^2	Model R^2
All Data					
Intercept	-532.891	238.529			
ASN (0-15 cm)	5.362	1.358	20.160*	0.309	0.309
Nitrate-N (0-60cm)	13.005	3.841	17.500*	0.134	0.443
Organic C (0-30 cm)	-7.047	3.432	13.925	0.500	0.493
Hepburn					
Intercept	3.022	0.676			
ASN (0-15 cm)	-0.009	0.003	9.286*		0.249
St. Dennis					
Intercept	2.859	0.589			
ASN (0-15 cm)	-0.008	0.003	10.615*		0.399
Watrous					
No significant relationships detected					

*Significant at < 0.0001 probability levels.

Summary

Canola yield response was largely a function of ASN. This contrasts the results of the wheat study in which a spring inorganic-N (NO_3^-), soil moisture (growing season precipitation, volumetric water content) and soil organic matter where found to be important soil variables describing wheat yields. The differences between the crops likely reflects different N uptake patterns and thus for wheat, N available during the early growing season (and largely accounted for by measuring spring inorganic N) predicts consequent yields whereas N released later in the growing season (and thus largely accounted for by estimating potentially available N using the

ASN test) was a more important predictor of canola yields. Relatively low R^2 values for the yield response functions of both wheat and canola indicates there is still a large amount of yield variability unaccounted for by any of the predictor variables.

In contrast to the observations for wheat, the significant correlation between ASN and yield response was relatively consistent between sites, indicating that ASN may be an applicable measure of soil N fertility for canola. As with wheat, additional research will be required before the ASN test can be adapted to canola production in Saskatchewan but results present compelling evidence that this measure of soil N may have a good application in further revising fertilizer recommendations for canola.

5) Assessment of the ASN test over a range of soil types and uses.

A controlled growth chamber experiment was conducted using a number of soils, representing different land uses to further confirm the suitability of the ASN test for Saskatchewan soils. Soils used in the growth chamber study represented a variety of land uses (i.e., agricultural and non-agricultural soils) and previous management history (i.e., fertilized, unfertilized and manured soils). The purpose of this study was to examine the relationship between various measures of soil N and yield of wheat, and to determine if the ASN test, in particular, could be used in a broad range of soils.

Materials and Methods

A total of 22 soil samples from various sites were collected in the fall of 2003. Soils #1 to 4 were collected from a research site in the St. Denis National Wildlife Area located approximately 40 km east of Saskatoon, Saskatchewan. The site is characterized by a hummocky terrain (moderate to slope steeps) with till material overlain by glaciolacustrine sediments, ranging in depth from a few centimeters to over two meters. Soils #5 to 16 were from a liquid swine manure research site west of Humboldt, Saskatchewan. Urea and manure have been applied annually for the previous seven years at a rate of 100kg N/ ha, with an unfertilized check also included in the randomized complete block design. The soils were formed on silty lacustrine parent materials and are classified within slope class 3. Soils #18 to 21 were collected from various positions in a minimum tillage field. Finally, soils #17 and 22 were collected from undisturbed native aspen and grassland areas, respectively.

The growth chamber experiment used a 16-h light cycle at 24°C (light intensity of approximately 45600-LUX), and an 8-h dark cycle at 20°C, with relative humidity maintained at 50%. Two N treatments, 0- and 150 mg N kg^{-1}, were replicated three times for each soil using a completely randomized design. Soil (1200g) was placed into 15 cm diameter pots and maintained at 85% field capacity for the duration of the study. In addition to the N treatments, basal application of nutrient solutions were added all pots as follows: 30µg P g^{-1} as $Ca(H_2PO_4)\cdot H_2O$, 50µg S g^{-1} as K_2SO_4, 200µg K g^{-1} as K_2SO_4 and KCl, 0.6µg Mo g^{-1} as $NaMoO_4\cdot 2H_2O$, 1.5µg B g^{-1} as H_3BO_3, 5µg Mn g^{-1} as $MnSO_4\cdot H_2O$, 4µg Zn g^{-1} as $ZnSO_4\cdot 7H_2O$, and 0.6µg Cu g^{-1} as $CuSO_4\cdot 5H_2O$. Ten wheat seeds were planted to a depth of approximately 2.5 cm, with plants being thinned to three plants per pot after emergence. Aboveground biomass of the plants was hand-harvested 48 days after planting when all plants had reached the heading stage. Dry weight biomass was recorded for each pot, and total N content was determined using dry combustion (LECO CNS-200 Autoanalyzer). Total N-uptake was determined by multiplying N concentration in the plant with biomass yield.

A number of soil properties were determined using standard analytical techniques including pH, electrical conductivity, available NO_3^-, ammonium (NH_4^+), ASN, sulphate-S, phosphate, and potassium. Total carbon C and N concentrations were determined through dry combustion using a LECO CNS-2000 analysis. Organic C was determined through dry combustion. Microbial biomass N (MBN) was determined following the method of Voroney et al. (1993).

Results and Discussion

Highly significant correlations were found between ASN and a number of soil variables (Table 11). In particular, ASN apparently was closely related to organic C (Fig.) and variables intrinsically related to organic C. If ASN is indeed a prediction of potentially mineralizable N, it is no surprise then that it is correlated to organic C and N levels, as sources of both C and N are required for microbial mineralization of N. However, the very high correlations may suggest that ASN provides no additional information over the other measurements.

Table 11. Pearson correlations coefficients among various soil N indices and selected soil properties.

	Org. C	Org. N	MBN	ASN	NO_3-N	NH_4-N	Spring Inorg. N
Total N	0.946**	0.980**	n.s.	0.962**	n.s.	n.s.	0.449*
Organic C		0.946**	n.s.	0.933**	n.s.	n.s.	n.s.
Organic N			n.s.	0.938**	n.s.	n.s.	n.s.
MBN				n.s.	n.s.	n.s.	n.s.
ASN					0.427*	n.s.	0.451*
NO_3-N						n.s.	0.994**
NH_4^+-N							n.s.

*, **, ***Significant correlations at the 0.05, 0.01 and 0.001 probability levels.

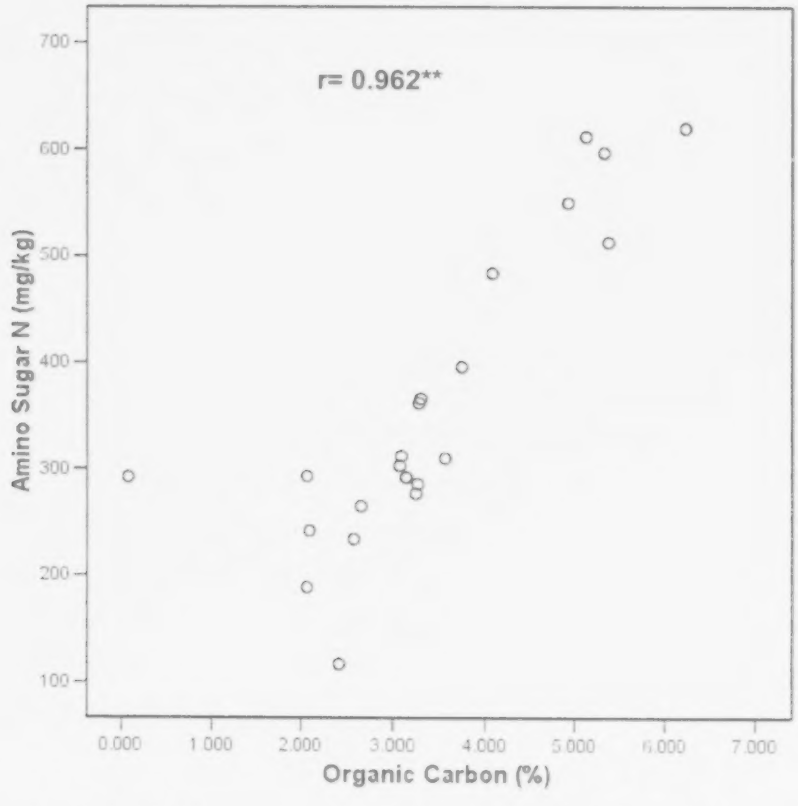

Figure 10. Relationship between ASN levels and yield of unfertilized (N) canola at three sites in Saskatchewan.

Total C and N, organic C and N, ASN, and NO_3^- were all significantly correlated with N-uptake for both the 0N and 150N treatments, although the correlation coefficients and significance level cropped for the 150N treatment (Table 12). The correlation of NO_3^- to N-uptake may indicate the importance of N availability early in the growing season, while the correlations with total and organic N and ASN emphasize the role of mineralization in N-uptake availability. No relationships were found between the previously mentioned variables and N-uptake response.

Table 12. Pearson correlation coefficients (R) for selected soil properties and N-uptake and yield of wheat.

	N-uptake			Yield		
	0N	150N	Response	0N	150N	Response
Total N	0.684**	0.500*	n.s.	0.534*	n.s.	-0.448*
Organic C	0.679**	0.532*	n.s.	n.s.	n.s.	-0.471*
Organic N	0.705**	0.555*	n.s.	0.503*	n.s.	-0.533*
MBN	n.s.[z]	n.s.	n.s.	n.s.	n.s.	n.s.
ASN	0.663**	0.515*	n.s.	0.506*	n.s.	n.s.
NH_4^+	n.s.	n.s.	n.s.	n.s.	n.s.	-0.593**
NO_3^-	0.615**	0.467*	n.s.	n.s.	n.s.	n.s.
Inorganic N	n.s.	n.s.	n.s.			

[z] Not significant, *,** Correlation significant at the 0.05 and the 0.01 level, respectively.

Total and organic N, as well as ASN, were the best predictors of yield for the 0N treatment (Table 12). There were no significant correlations between any of the soil measurements and 150N yield. However, total N, organic C and N, and NH_4^+ all had significant negative correlations with biomass yield response, with ammonium having the strongest relationship. Interestingly, there was no significant relationship between ASN and yield response o wheat, again suggesting that the ability of a soil N test to predict crop response may be controlled largely by the pattern of crop N uptake. These growth chamber results are in agreement with the data for wheat field study.

It is interesting that ammonium was well correlated to N-uptake response and yield response. The NH_4^+ in the soils at the initiation of the experiment likely was converted rapidly to NO_3^-, particularly given the ideal temperature and moisture conditions fro mineralization

associated with the growth chamber conditions. Thus, the NH_4^+ pool was apparently a major contributor to plant available N. Moreover, the strength of the relationship was likely enhanced by the inclusion of previously manured soils in the experiment.

Much higher correlations were obtained between soil N indices and N-uptake and yield than have been reported for field studies (Walley et al. 2002). This is likely a result of eliminating or at least minimizing the variability associated with temperature and moisture. However, the total variability in yield and N-uptake accounted for by the soil analyses was still quite low and clearly indicates that although appropriate oil N availability indices can provide important information regarding crop response to fertilizer N inputs, we must remain realistic in our expectations regarding our ability to predict crop yields based on a limited suite of soil information.

We attempted to compare our results with those of Khan et al. (2001) who used ASN levels to classify soils as either responsive or non-responsive based on the critical level of 225 to 235 mg N kg^{-1} (Figure 11). Based on the 22 samples used in our experiment, we were unable to satisfactorily identify a critical ASN levels to clearly delineate the soil as responsive. However, data from the field studies with wheat and canola suggest that the ASN test may be more appropriate for crops that can respond to mineralized N later in the growing season, such as canola. Gelderman et al. (1988) suggested that differences in the growth patterns of crops would determine the relationship between mineralizable N indices and N-uptake, with mineralizable N being better utilized by warm-season crops such as corn, as compared to a fast-growing, cool-season crop such as wheat. In research that followed their original work on ASN, Khan et al. (2002) concluded that normal growing conditions must be assumed in order for the ASN test to correctly distinguish between responsive and non-responsive sites. Although their work was examining the validity of the ASN test under drier than normal conditions (Khan et al. 2002), the same concerns may arise in wetter than normal conditions. In the same respect that poor moisture conditions limit the mineralization of ASN (Khan et al. 2002), higher than normal moisture conditions would stimulate N-mineralization in soils. This may help to explain the lack of responsiveness observed in the growth chamber study, where soils were held at a much higher moisture level than would be typical of the semi-arid environment from which they were obtained.

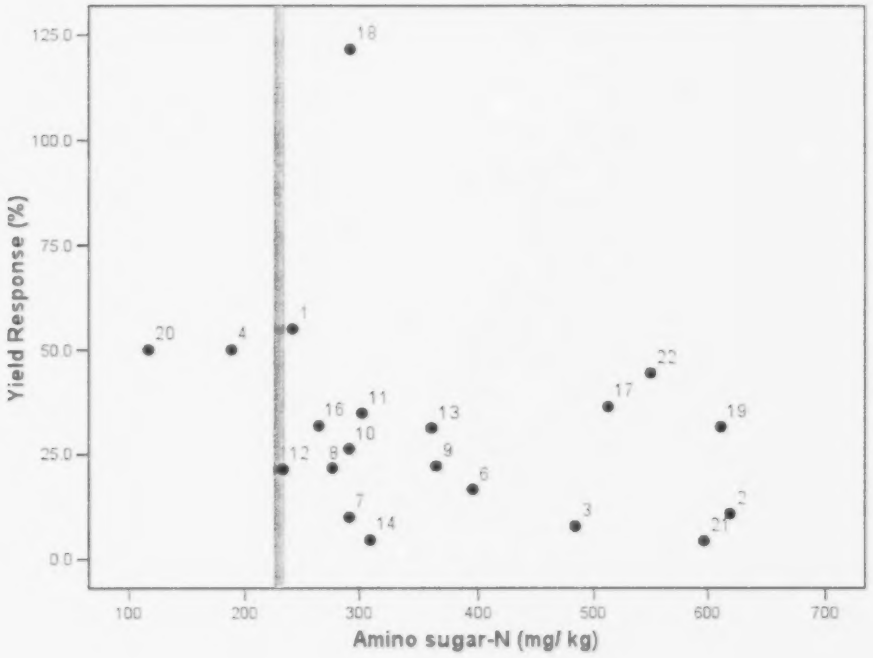

Figure 11. Relationship between ASN and yield response of wheat to N fertilizer. The vertical line indicates the critical level level according to Khan et al. (2001).

Land Management Influences on ASN and Yield Response

To further examine the relationship between ASN and yield response, sites were divided into four land management groups: slough (soils #2, 3, 21), manured (soils #6, 7, 8), cultivated (soils #1, 9, 10, 11, 12, 13, 14, 16, 18, 19, 20), and permanent vegetation (soils #4, 17, 22) (Fig. 12). Slough soils, regardless of the type of vegetation, had the highest average ASN levels, with permanent vegetation soils falling into its lower range of values. The high degree of variability in permanent vegetation soils can be attributed to soil #4, which was a 20-year bromegrass site. This soil is characterized by low total and organic C and N values, contrary to the other permanent vegetation sites. Cultivated and manured soil had very similar ranges and median values for ASN.

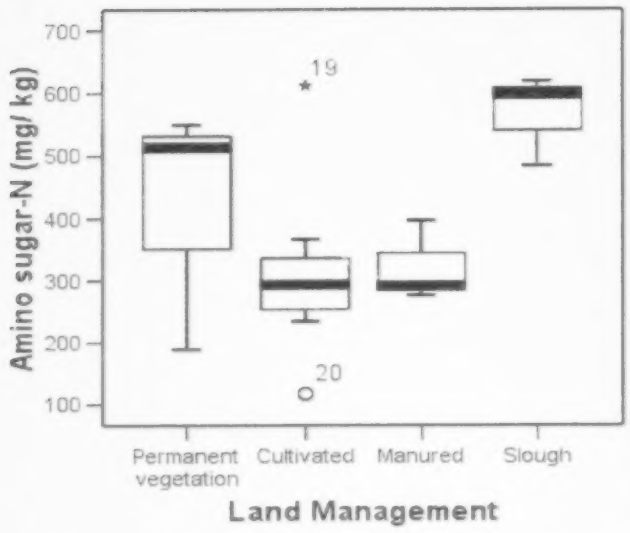

Figure 12. Variability in ASN according to land management classification. Outliers are labeled with soil identification number.

Conclusion

Amino sugar N is highly correlated to total and organic C and N contents. The lack of correlation of NO_3^- and NH_4^+ with measures of total or organic N stress the fact that inorganic measurements of N do not reflect the N mineralization potential of soils. All soil indices examined showed some correlation to either N-uptake or yield except for MBN. Ammonium was the only soil N index correlated to both N-uptake response and yield response. The relatively poor correlations between soil indices and crop growth indicators illustrates the high degree of complexity between soil factors and plant production.

Although ASN was unable to distinguish between responsive and nonresponsive soils in this experiment, this test may still have the potential to be used as a predictor of yield response for certain soils, crops, or growing conditions. Future research of ASN should expand to include numerous crops grown in field conditions on a wide range of soil types, landscape positions, and under differing land management practices.

The immense complexity of soil and plant processes limits the usefulness of a single measure of N availability to predict either crop yield or N-uptake. Rather, the appropriate indices need to be used in combination with other variables (i.e., soil moisture availability) and as tools in the development of fertilizer strategies in order to obtain maximum yields while minimizing losses via leaching, denitrification, and immobilization.

References

Gelderman, R.H., Dahnke, W.C. and Swenson, L. 1988. Correlation of several soil N indices for wheat. Commun. Soil Sci. Plant Anal. 19: 755-772.

Gianello, C., and J.M. Bremner. 1986. A simple chemical method of assessing potentially avaiulable organic nitrogen in soil. Comm. Soil Sci. Plant Anal. 17:195-214.

Jalil, A., C.A. Campbell, J. Schoenau. J.L. Henry, Y.W. Jame, and G.P. Lafond. 1996. Assessment of two chemical extraction methods as indices of available nitrogen. Soil Sci. Soc. Am. J. 60:1954-1960.

Johnston, A.M. and Fowler, D.B. 1992. Response of no-till winter wheat to nitrogen fertilization and drought stress. Can. J. Plant Sci. 72:1075-1089.

Keeney, D.R. 1982. Nitrogen-availability indices. p. 711-734. *In* A.L. Page (ed.) Methods in soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Keeney, D.R., and D.W. Nelson. 1982. Nitrogen – Inorganic forms. p. 643-698. *In* A. L. Page (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Khan, S.A., R.L. Mulvaney, and R.G. Hoeft. 2001. A simple test for detecting sites that are nonresponsive to nitrogen fertilizer. Soil Sci. Soc. Am. J. 65:1751-1760.

Khan, S.A., R.L. Mulvaney, and R.G. Hoeft. 2002. A rational basis for the lack of N-fertilizer responsiveness in a good growing season. *In* Illinois Fertilizer Conference Proceedings, Peoria, Illinois. 21-23 January 2002. Available online at http://frec.cropsci.uiuc.edu/2002/report7/index.htm (verified 13 October 2005).

Mulvaney, R.L., S.A. Khan, R.G. Hoeft, and H.M. Brown. 2001. A soil organic nitrogen fraction that reduces the need for nitrogen fertilization. Soil Sci. Soc. Am. J. 65:1164-1172.

Pennock, D.J. and F.L. Walley. 2000. Development and extension of precision farming techniques for Saskatchewan producers. Agri-Food Innovation Fund. Project 96000130Res/ 07FE, ADF Final Report. March 31, 122pp. Available online at http://www.agr.gov.sk.ca/afif/Projects/19960130.pdf (verified 13 January 2005).

Qian, P., and J.J. Schoenau. 1995. Assessing nitrogen mineralization from soil organic matter using anion exchange membranes. Fert. Res. 40:143-148.

Qian, P., and J.J. Schoenau. 1997. Recent developments in use of ion exchange membranes in agriculture and environmental research. Recent Developm. Soil Sci. 1:43-45.

Soper, R.J. and P.M. Huang. 1963. The effect of nitrate nitrogen in the soil profile on the response of barely to fertilizer nitrogen. Can. J. Soil Sci. 43: 350-358..

Voroney, R.P., Winter, J.P. and Beyaert, R.P. 1993. Soil microbial biomass C and N. Pages 277-286 *in* M.R. Carter (ed.) Soil sampling and methods of analysis, Lewis Publishers, Boca Raton, FL.

Walley, F., T. Yates, J-W. van Groenigen, and C. van Kessel. 2002. Relationships between soil nitrogen availability indices, yield, and nitrogen accumulation of wheat. Soil Sci. Soc. Am. J. 66:1549-1561.

Walley, F., D. Pennock, M. Solohub, and G. Hnatowich. 2001. Spring wheat (*Triticum aestivum*) yield and grain protein responses to N fertilizer in topographically defined landscape positions. Can. J. Soil Sci. 81: 505-514.

Wang, W., C.J. Smith, P.M. Chalk, and D. Chen. 2001. Evaluating chemical and physical indices of nitrogen mineralization capacity with an unequivocal reference. Soil Sci. Soc. Am. J. 65:368-376.

Yates, T. 2001. The spatial distribution of soil nitrogen availability. M.Sc. Thesis, Department of Soil Science, University of Saskatchewan, Saskatoon, SK.

(d) EQUIPMENT - none.

(e) PROJECT DEVELOPED MATERIALS –

Walley, F.L., T. Yates, A. Jokic and M. Masutti. 2003. Assessing Soil N Availability Indices - Is Inorganic N Enough? Proceedings of the 2003 Soils and Crops Workshop, University of Saskatchewan, Saskatoon, SK, February 17-18.

(f) PROJECT PHOTOS – None.

(g) ACKNOWLEDGMENT – I was invited to discuss the topic of soil N availability indices and describe our research at a number of different agronomist meetings (Manitoba Agronomists Conference 2002, 2003 CAAR Crop Management Forum, the 2003 Western Canada Agronomy Workshop, 2005 Saskatchewan Soil Conservation Association Annual Conference and the 2005 Canola College) and presented a volunteered paper with some preliminary findings at a fourth meeting (Soils and Crops Workshop, 2003). Additionally, a graduate student (Shelagh Torrie) working on this project presented posters at both the 2004 American Society of Soil Science meetings and the 2005 Soils and Crops Workshop. The support from the Government of Saskatchewan, ADF, was acknowledged in these presentations.

(h) ICAR DATA ENTRY - This project was entered into the data base.